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ABSTRACT

Forty-eight first and second graders were taught an algorithm for solving concept-attainment problems. Using a 2 x 2 factorial design, a comparison was made of the effects of (a) reverse versus forward sequencing of instruction and (b) elicited verbalization of the algorithm versus nonverbal practice. Reverse groups outperformed forward groups on the memory-free test as predicted, but not on the memory-dependent test or the transfer test. No significant differences resulted from the verbalization factor. (Author/MS)

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THE EFFECTS OF REVERSE INSTRUCTIONAL SEQUENCING AND ELICITED VERBALIZATION ON LEARNING A PROBLEM SOLVING ALGORITHM

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The primary motivation of this study was a desire to resolve a dilemma which students often experience while attempting to learn a complex rule-governed procedure. Stated in inelegant terms, the dilemma can be posed as this student question about instruction: How can I patiently sit back and attempt to master the basics when I fail to see where all this is leading and what I'm supposed to be able to do when I'm through? This question raises the main issue addressed in this study: Is it beneficial to reverse the usual sequence of instruction so that students begin with the final operation in a complex procedure, gain an overview of the interrelationship of component operations, and see the end from the beginning? The primary purpose of this study was to compare forward and reverse instructional sequencing in teaching first and second graders a complex information-processing procedure. It was postulated that reverse sequencing would provide a superior overview of the structure of the problem-solving algorithm and thus facilitate mastery of the problem-solving procedure.

Glaser (1973) has questioned whether a Gagne-type hierarchy (Gagne, 1968) must necessarily be learned in a hierarchical order from bottom to top. Gagne, himself, questions whether the learning hierarchy necessarily suggests the presentation sequence for instruction (Gagne, 1968). Landa (197·) advocates the teaching of algorithms (procedures) for problems that require a sequence of operations in order to find a solution to the problem. Blake, Osguthorpe, and

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Merrill (1975) found that an algorithmic procedure for classifying instances of trochaic meter in poetry was more effective than a non-algorithmic presentation of the critical attributes. P. F. Merrill (1971) has made a distinction between an information processing procedure such as summing an arithmetic series and a behavioral chain such as tying a shoelace or reciting a poem from memory. Although both types of behavior involve a particular stimulus serving as a stimulus for the next in a linked series, there are important differences. In a behavioral chain like tying a shoe, the output is invariant. Information processing procedures such as summing an arithmetic series incorporate branching rules which differentially manipulate information flowing into a decision point.

Several studies employing an information-processing task have investigated the effectiveness of the backward-chaining techniques advocated by Gilbert (1962) and Mechner (1967). These studies (Niedermeyer, Brown, and Sulzen, 1969; Olivier, 1971; Scott, 1969; Wilcox, 1974) indicate that directionality of sequence is not important provided contiguous operations in the information-processing procedure are taught one after another consistently in the same order. It was not clear, however, whether any of the reverse sequence groups in these studies actually previewed the overall structure of the algorithm they were using. Neither the forward nor the reverse groups in these studies may have had the opportunity to develop a conceptual framework for the total task at the beginning of instruction. The present study attempted to compensate for these deficiencies by allowing the reverse groups to view the step-by-step manipulation of data in each successive operation leading up to the operation they were learning; that is, they saw a dynamic representation of how the output for each operation was derived, rather than simply seeing the cumulative output of previous operations.

A secondary purpose of the study was to investigate the effect of having the learner explicitly verbalize the sequence of information-processing operations involved in problem solution as a way of stimulating the development of an

effective retrieval strategy for the algorithm. Berry (1964) advocated letting the teacher pretend to be a computer and letting children give him explicit directions for performing information-processing tasks. He reasoned that such a strategy should increase the capability of the child to modify his own cognitive operations to meet the processing requirements of the task and should allow the teacher to assess the extent to which the child has control over the necessary operations.

Even though Berry does not provide research evidence to support his instructional strategy, three studies dealing with the learning of noun pairs (Bobrow and Bower, 1969; Anderson, Goldberg, and Hidde, 1971) suggest that when children generate sentences or words at the end of sentences to assist them in the recall of noun-pairs the recall task is learned more effectively and efficiently. In all three studies the task required more than the simple memorizing of a verbal chain. Sentences or words generated by the children had to take into account the differential inputs into the information-processing procedure. In addition, the decision rules in the procedures required children to branch to different operations based on the particular characteristics of the input data. Based on these studies, the present investigation postulated that the verbalization requirement would enhance recall of the steps of the algorithm as well as their sequence of occurrence. This study investigated the effects of verbalization on recall of an algorithm that required the learner to use constantly changing data relating to the output of each operation in the algorithm.

Method

The problem-solving algorithm.--First and second graders in this study were taught a 12-step algorithm for solving any one of a set of concept attainment problems relating to the one or more attributes that constituted the E's

"secret" in a given array of cards. One array of 8 cards varied the three attributes number (2 and 4), color (green and orange), and shape (circle and triangle). Each 2 x 3 card in the 8-card array consisted of one variation of all three attributes (e.g., 2 orange circles, 4 green triangles). A second array of 16 cards varied the four attributes number (1 and 3), color (yellow and blue), shape (oval and diamond), and design (stripes and spots). Each 2 x 2 card in the 16-card array consisted of one variation of all four attributes (e.g., 1 blue diamond with stripes, 3 yellow ovals with spots). In the terminal problem E placed a marker on one of the cards in the 8-card or the 16-card array that showed his "secret." The child was instructed to pick cards to figure out the secret. Each time the child picked up a card he asked E: "Does this show your secret?" E replied "yes" or "no." The "secret" could be one attribute on the marked card (e.g., the number 2), two attributes on the card (e.g., 2 orange), three attributes on the card (e.g., 2 orange triangles), or all cards in the display (the attributes on each card were printed on a black background). The 16-card array could have as many as four attributes in E's secret (e.g., 3 blue ovals with stripes). The child was taught an algorithm (information-processing procedure) that would help him systematically and conservatively infer E's secret each time by locating and asking about three other minimally different cards in the three-attribute array, or four other cards in the four-attribute array. An information processing array was used in conjunction with the card arrays during instruction to teach the child the steps in the algorithm. It consisted of a black and white train for each attribute varied in the problems (i.e., number, color, shape, design). Each train had one engine, two cars, and a caboose. Each car on the attribute trains had a white one-inch square area for storing the values of the stimulus variables for a particular card array.

Design and subjects.--The two factors of instructional sequence and verbalization with two levels to each factor resulted in a 2 x 2 factorial design with four treatment conditions, forward sequence-no verbalization (treatment F), forward sequence-verbalization (treatment FV), reverse sequence-no verbalization (treatment R), and reverse sequence-verbalization (treatment RV). The subjects were 48 children who had just completed first or second grade at a predominantly middle-class school in a city of 30,000 in the Rocky Mountain area. The children were randomly assigned by sex and grade to the treatment conditions. Table 1 shows the number of children by grade and sex in each of the four treatment conditions.

TABLE 1

Number of Subjects
by Treatment, Sex,
and Grade

TREATMENT	FIRST GRADE		SECOND GRADE		TOTALS
	M	F	M	F	
FORWARD (F)	4	4	4	4	12
FORWARD VERBALIZ. (FV)	4	4	4	4	12
REVERSE (R)	4	4	4	4	12
REVERSE VERBALIZ. (RV)	4	4	4	4	12
TOTALS	12	12	12	12	48

Training was presented by 12 volunteer tutors who were high school students or recent high school graduates. E's were randomly assigned to treatments (3 tutors to each treatment) and trained by the principal investigator.

Treatments.--Children in the two forward treatment groups (F and FV) learned the component operations of the problem solving algorithm in the same order as the information must be processed when applying the solution algorithm to concept attainment problems. Children in the other two treatment groups (R and RV) learned the component operations in a reversed sequence. The one exception to this general rule was the final operation of conjoining attribute values and verbalizing the secret. Both forward and reversed treatments began by teaching this skill. There were four lessons in each treatment group with one to four operations introduced per lesson. Each lesson consisted of the demonstration by E of the operation(s) introduced in the lesson, followed by opportunity for the child to practice the lesson operations. Children in the two verbalization treatments (FV and RV) pretended they were teaching the operations in the lesson to E during the practice items, while subjects in the two nonverbalization treatments engaged in similar practice items but did not verbalize what they were doing during practice.

Procedure.--Each child was trained by a single experimenter. The training was given in the child's own home over a four-day period with one lesson per day. Post-testing was conducted over a four-day period, beginning the day after the last day of training, in classrooms at the elementary school where the children were enrolled. Each child was tested individually by graduate students with previous experience in psychological testing who had taken no part in the training.

Dependent measures.--The primary dependent measures included a transfer test, a test of memory-dependent problem solving, a test of memory-free problem

solving, and trials to criterion on the practice steps of the three lessons where treatment differences were manifested.

The transfer test consisted of eight concept-attainment problems involving a dish array rather than a card array. Eight plain white plates, each about 5 inches in diameter, were arranged in two rows of four each in front of the child. The objects on the plates varied in the three attributes of size (big or little), material (cloth or wood), and shape (star or square). These attributes were entirely different from those used during training. All objects were glued securely to the center of the plates. Each dish could show any one of eight possible secrets: little, cloth, star, little-cloth, little-star, little-cloth-star, or all the dishes. The child was invited to find E's secret by varying one attribute at a time and asking about the three trial instances which differ minimally from the focus instance. The child did not have an information-processing array (i.e., the train board) to use as a memory aid in following through the steps of the problem solving algorithm. It was necessary for the child to store information in his head instead of on the information-processing array. This "in the head" solution had been taught during the last lesson of training to all subjects.

The memory-dependent test also had eight problems. An eight-card array was used similar to the eight-card array used in training. The attributes varied on this test were similar to those varied during training (i.e., number, color, shape). The instance combinations of the attributes varied, however, with numbers including one and two, color including orange and blue, and shape including oval and triangle. As in the transfer test, the child was expected to determine E's secret without the use of the train board as a memory aid.

The memory-free test was the only one of the three posttests where the children were allowed to use the information-processing array. A 16-card

array was used for problem presentation made up of attributes which had been manipulated during training, but in a novel combination. The attributes varied were number (two, three), color (green, yellow), shape (circle, triangle), and design (stripes, spots). The test consisted of 10 problems. The child could use the trainboard to store information for the problem-solving algorithm rather than storing the information in his head.

The final dependent measure was the number of trials to criterion on the practice steps of three of the four training lessons. Experimenters were given printed logs which listed each practice step and numbers corresponding to the practice examples. They coded each trial according to whether S solved the problem without help or made an incorrect response/received help. The number of trials required to reach the mastery criterion was recovered from this data.

Analysis.--The data were analyzed in several ways in order to identify the precise effects of sequence and verbalization. Because of expected interrelationships among the dependent measures, the output variables were first considered collectively in a multivariate analysis of variance. In order to pinpoint the effects of the treatment factors on single output variables, a number of univariate analyses of variance were also performed.

Results

In the multivariate analysis of variance for trials to criterion, transfer, score, memory-dependent score, memory-free score, and proportions of conservative, probabilistic, and redundant trial card choices on the memory-free test, no significant effects for sequence or verbalization were found, nor were there any other significant main effects or interactions.

When univariate analyses of variance were performed the most noteworthy finding on the posttests was the effect of the sequence factor on the memory-free

test scores (see Figure 1). Reverse groups (R, RV) had a mean percentage correct of 70.8 on the memory-free test compared with 51.7 percent for the forward groups (F, FV). However, statistical difference at the .05 level was not achieved due to the limited degrees of freedom for testing the main effects and the relatively large variation among tutors, $F(1,8)=4.41$, $.05<p<.10$ (F-ratio of 5.32 required for significance at the .05 level). There were no significant differences resulting from the verbalization factor on any of the posttests.

FIGURE 1 HERE

Conclusions

The postulate that reverse sequencing would facilitate mastery of the task was not supported by the findings although the trend approached significance on the memory-free test. There was no evidence that verbalizing explicit directions for an algorithmic procedure facilitates recall. While the means on the transfer test favored the verbalization groups, the differences were not significant. Therefore, both hypotheses postulated in this study were rejected.

A follow-up to the present study should explore the interaction of chunking and sequence. If a concept-attainment task is employed, a representative variety of attributes and stimulus arrays would be used as problem exemplars and a single algorithm should be used for both memory-free and memory-dependent problems. It also would be well to explore a diverse type of task involving an information-processing procedure with a larger and more complex series of operations.

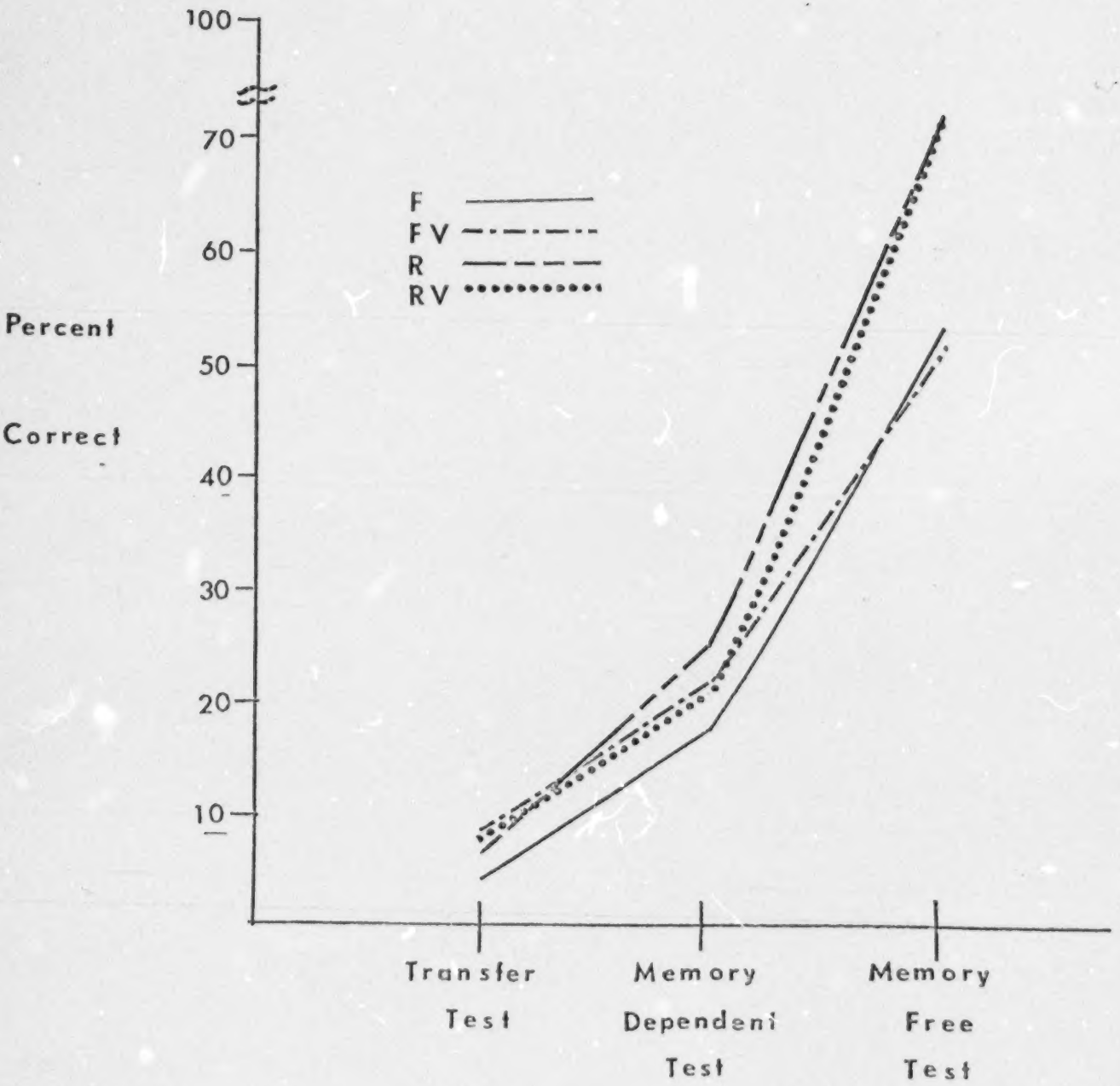

Figure 1

Posttest Mean Scores

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